

## CLAIMS

Having thus described our invention in detail, what we claim as new and desire to secure by the Letters Patent is:

- 1 1. A porous, low-k dielectric film comprising:
  - 2
  - 3 a first phase of monodispersed pores having a diameter of from about 1 to about 10
  - 4 nm that are substantially uniformly spaced apart and are essentially located on sites of
  - 5 a three-dimensional periodic lattice; and
  - 6
  - 7 a second phase surrounding said first phase, wherein said second phase is a solid phase
  - 8 which includes (i) an ordered element that is composed of nanoparticles having a
  - 9 diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart
  - 10 and are essentially arranged on sites of a three-dimensional periodic lattice, and (ii) a
  - 11 disordered element comprised of a dielectric material having a dielectric constant of
  - 12 less than about 2.8.
- 1 2. The porous, low-k dielectric film of Claim 1 wherein said nanoparticles are
- 2 comprised of Si, C, O and H.
- 1 3. The porous, low-k dielectric film of Claim 1 wherein said film has an effective
- 2 dielectric constant of less than about 2.0.
- 1 4. The porous, low-k dielectric film of Claim 1 wherein said film has an effective
- 2 dielectric constant of about 1.8 or less.
- 1 5. The porous, low-k dielectric film of Claim 1 wherein said monodispersed pores
- 2 have a diameter of from about 1 to about 5 nm.

1       6. The porous, low-k dielectric film of Claim 5 wherein said monodispersed pores  
2       have a diameter of about 3 nm.

1       7. The porous, low-k dielectric film of Claim 1 wherein said pores are separated by a  
2       center-center distance  $V_{cc}$ .

1       8. The porous, low-k dielectric film of Claim 7 wherein  $V_{cc}$  between each pore is  
2       from about 2 to about 10 nm.

1       9. The porous, low-k dielectric film of Claim 8 wherein  $V_{cc}$  between each pore is  
2       from about 3 to about 6 nm.

1       10. The porous, low-k dielectric film of Claim 1 wherein said pores are separated by  
2       an edge-edge distance  $V_{ee}$ .

1       11. The porous, low-k dielectric film of Claim 10 wherein  $V_{ee}$  between each pore is  
2       from about 1 to about 8 nm.

1       12. The porous, low-k dielectric film of Claim 11 wherein  $V_{ee}$  between each pore is  
2       from about 2 to about 5 nm.

1       13. The porous, low-k dielectric film of Claim 1 wherein said pores and said  
2       nanoparticles are separated by a distance AB.

1       14. The porous, low-k dielectric film of Claim 13 wherein AB is from about 1 to  
2       about 10 nm.

1       15. The porous, low-k dielectric film of Claim 14 wherein AB is from about 2 to  
2       about 50 nm.

- 1       16. The porous, low-k dielectric film of Claim 1 wherein said nanoparticles have a  
2       diameter of from about 2 to about 3.0 nm.
- 1       17. The porous, low-k dielectric film of Claim 1 wherein said low-k dielectric binder  
2       has a dielectric constant of about 2.8 or less.
- 1       18. The porous, low-k dielectric film of Claim 1 wherein said low-k dielectric binder  
2       is selected from the group consisting of polyarylene ethers, thermosetting polyarylene  
3       ethers, aromatic thermosetting resins, Si-containing polymers, amorphous alloys  
4       comprised of Si, C, O and H that may, or may not, be doped with oxide,  
5       methylsilsesquioxane (MSQ), hydrogensilsesquioxane (HSQ), phenylsilsesquioxane  
6       (PSQ), and mixtures or complexes thereof.
- 1       19. The porous, low-k dielectric film of Claim 18 wherein said low-k dielectric binder  
2       is MSQ, HSQ, PSQ or a mixture of MSQ and HSQ.
- 1       20. The porous, low-k dielectric film of Claim 1 wherein said film has a hardness of  
2       about 0.2 GPa or greater.
- 1       21. The porous, low-k dielectric film of Claim 20 wherein said film has a hardness of  
2       from about 0.2 to about 0.4 GPa.
- 1       22. The porous, low-k dielectric film of Claim 1 wherein said film has a Modulus of  
2       about 2.0 GPa or greater.
- 1       23. The porous, low-k dielectric film of Claim 22 wherein said film has a Modulus of  
2       from about 2 to about 4 GPa.
- 1       24. An interconnect structures which includes at least a porous, low-k dielectric film  
2       formed between metal wiring features, wherein said porous, low-k dielectric film

3 comprises a first phase of monodispersed pores having a diameter of from about 1 to  
4 about 10 nm that are substantially uniformly spaced apart and are essentially located  
5 on sites of a three-dimensional periodic lattice; and a second phase surrounding said  
6 first phase, wherein said second phase is a solid phase which includes (i) an ordered  
7 element that is composed of nanoparticles having a diameter of from about 1 to about  
8 10 nm that are substantially uniformly spaced apart and are essentially arranged on  
9 sites of a three-dimensional periodic lattice, and (ii) a disordered element comprised of  
10 a dielectric material having a dielectric constant of about 2.8 or less.

1 25. The interconnect structure of Claim 24 wherein said nanoparticles are comprised  
2 of Si, C, O and H.

1 26. The interconnect structure of Claim 24 wherein said film has an effective  
2 dielectric constant of less than about 2.0.

1 27. The interconnect structure of Claim 26 wherein said film has an effective  
2 dielectric constant of about 1.8 or less.

1 28. The interconnect structure of Claim 24 wherein said monodispersed pores have a  
2 particle diameter of from about 1 to about 5 nm.

1 29. The interconnect structure of Claim 24 wherein said monodispersed pores have a  
2 particle diameter of about 3 nm.

1 30. The interconnect structure of Claim 24 wherein said pores are separated by a  
2 center-center distance  $V_{cc}$ .

1 31. The interconnect structure of Claim 30 wherein  $V_{cc}$  between each pore is from  
2 about 2 to about 10 nm.

1    32. The interconnect structure of Claim 31 wherein  $V_{cc}$  between each pore is from  
2    about 3 to about 6 nm.

1    33. The interconnect structure of Claim 24 wherein said pores are separated by an  
2    edge-edge distance  $V_{ee}$ .

1    34. The interconnect structure of Claim 33 wherein  $V_{ee}$  between each pore is from  
2    about 1 to about 8 nm.

1    35. The interconnect structure of Claim 34 wherein  $V_{ee}$  between each pore is from  
2    about 2 to about 5 nm.

1    36. The interconnect structure of Claim 24 wherein said pores and said nanoparticles  
2    are separated by a distance AB.

1    37. The interconnect structure of Claim 36 wherein AB is from about 1 to about 10  
2    nm.

1    38. The interconnect structure of Claim 37 wherein AB is from about 2 to about 5 nm.

1    39. The interconnect structure of Claim 24 wherein said nanoparticles have a diameter  
2    of from about 2 to about 3.0 nm.

1    40. The interconnect structure of Claim 24 wherein said low-k dielectric binder has a  
2    dielectric constant of about 2.8 or less.

1    41. The interconnect structure of Claim 24 wherein said low-k dielectric binder is  
2    selected from the group consisting of polyarylene ethers, thermosetting polyarylene  
3    ethers, aromatic thermosetting resins, Si-containing polymers, amorphous alloys  
4    comprised of Si, C, O and H that may, or may not, be doped with oxide,

5       methylsilsesquioxane (MSQ), hydrogensilsesquioxane (HSQ), phenylsilsesquioxane  
6       (PSQ), and mixtures or complexes thereof.

1       42. The interconnect structure of Claim 41 wherein said low-k dielectric binder is  
2       MSQ, HSQ, PSQ or a mixture of MSQ and HSQ.

1       43. The interconnect structure of Claim 24 wherein said metal wiring features are  
2       metal lines or vias.

1       44. The interconnect structure of Claim 24 wherein said metal wiring features are  
2       composed of a conductive metal selected from the group consisting of Cu, Al, W, Pt  
3       and alloys or combinations thereof.

1       45. The interconnect structure of Claim 24 further comprising a substrate.

1       46. The interconnect structure of Claim 45 wherein said substrate is a semiconductor  
2       wafer, a dielectric layer, a barrier layer or a combination thereof.

1       47. The interconnect structure of Claim 24 wherein said structure is a dual damascene  
2       structure.

1       48. The interconnect structure of Claim 24 wherein said structure is a gapfill  
2       structure.

1       49. A method of fabricating a porous, low-k dielectric film comprising the steps of:  
2  
3       (a) coating a suspension of water soluble or water vapor soluble oxide particles with a  
4       surface ligand group which is effective in preventing agglomeration of said water  
5       soluble or water vapor soluble oxide particles, yet maintains solubility of the oxide

6 particles in said suspension, while separating forming monodispersed SiCOH particles  
7 having a particle diameter of from about 1 to about 10 nm;

8

9 (b) adding said coated water soluble or water vapor soluble oxide particles and said  
10 monodispersed particles to a solution containing a dielectric binder material having a  
11 dielectric constant of about 2.8 or less so as to form a precursor mixture;

12

13 (c) coating said precursor mixture on to a surface of a substrate;

14 (d) subjecting said coated precursor mixture to a curing process, said curing process  
15 including at least a step which is capable of ordering of said particles in a three-  
16 dimensional lattice and a step of forming a crosslinked film;

17

18 (e) removing said coated water soluble or water vapor soluble oxide particles from  
19 said crosslinked film so as to form pores in said film; and

20

21 (f) annealing said film containing said pores so as to remove residual water and  
22 hydroxyl groups from said film, wherein said film comprises a first phase of  
23 monodispersed pores having a diameter of from about 1 to about 10 nm that are  
24 substantially uniformly spaced apart and are essentially located on sites of a three-  
25 dimensional periodic lattice; and a second phase surrounding said first phase, wherein  
26 said second phase is a solid phase which includes (i) an ordered element that is  
27 composed of nanoparticles having a diameter of from about 1 to about 10 nm that are  
28 substantially uniformly spaced apart and are essentially arranged on sites of a three-  
29 dimensional periodic lattice, and (ii) a disordered element comprised of said binder.

1 50. The method of Claim 49 wherein said monodispersed particles are comprised of  
2 Si, C and H and said nanoparticles are comprised of Si, C, O and H.

1 51. The method of Claim 49 wherein said oxide particles are silicon oxide,  
2 germanium oxide, or mixtures thereof.

1       52. The method of Claim 49 wherein said suspension includes a solvent selected from  
2       the group consisting of an alcohol, an alkane, a ketone, an ether, an aromatic, and a  
3       carboxylic acid.

1       53. The method of Claim 49 wherein said surface ligand group is selected from the  
2       group consisting of an organosilane, an organohalosilane, germanium analogs of said  
3       organosilane or organohalosilane, long chain carboxylic acids containing from 4 to 18  
4       carbon atoms, long chain alcohols containing from 4 to 18 carbon atoms, long chain  
5       alkylamines containing from 4 to 18 carbon atoms, long chain phosphonic acids  
6       containing from 4 to 18 carbon atoms, and long chain sulfonic acids containing from 4  
7       to 18 carbon atoms.

1       54. The method of Claim 49 wherein said dielectric binder is selected from the group  
2       consisting of polyarylene ethers, thermosetting polyarylene ethers, aromatic  
3       thermosetting resins, Si-containing polymers, amorphous alloys comprised of Si, C, O  
4       and H that may, or may not, be doped with oxide, methylsilsesquioxane (MSQ),  
5       hydrogensilsesquioxane (HSQ), phenylsilsesquioxane (PSQ), and mixtures or  
6       complexes thereof.

1       55. The method of Claim 54 wherein said dielectric binder is MSQ, HSQ, PSQ or a  
2       mixture of MSQ and HSQ.

1       56. The method of Claim 49 wherein said coating step is a spin-coating process.

1       57. The method of Claim 49 wherein said curing process includes an optional hot  
2       bake process.

1       58. The method of Claim 57 wherein said optional hot bake process is carried out on a  
2       hot plate in air at a temperature of from about 80° to about 200°C for a time period of  
3       from about 1 to about 10 minutes.

- 1       59. The method of Claim 49 wherein said ordering curing step is carried out in a  
2       furnace using an inert ambient that includes less than about 50 ppm O<sub>2</sub> or H<sub>2</sub>O.
- 1       60. The method of Claim 59 wherein said ordering curing step is carried out at a  
2       temperature of from about 200° to about 300°C for a time period of from about 30 to  
3       about 120 minutes.
- 1       61. The method of Claim 49 wherein said crosslinking curing step is carried out at a  
2       temperature of from about 350° to about 450°C for a time period of from about 60 to  
3       about 240 minutes.
- 1       62. The method of Claim 49 wherein step (e) includes immersing said crosslinked  
2       film in water or exposing said crosslinked film to water vapor.
- 1       63. The method of Claim 49 wherein said annealing step out in a furnace using an  
2       ambient that includes less than about 50 ppm O<sub>2</sub> or H<sub>2</sub>O.
- 1       64. The method of Claim 63 wherein said annealing step is carried out at a  
2       temperature of from about 200° to about 400°C for a time period of from about 60 to  
3       about 240 minutes.
- 1       65. The method of Claim 49 wherein step (a) includes injecting 1 to 5 weight % of a  
2       solution containing a silicon precursor into a hot solution containing said surface  
3       ligand and an organic solvent containing between 0.1 to 1 % water.
- 1       66. The method of Claim 65 wherein said silicon precursor is a siloxane or a  
2       silsesquioxane.